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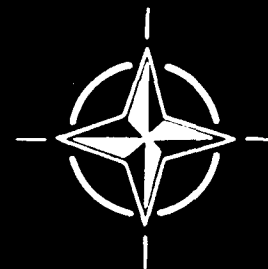
ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD ADVISORY REPORT No.277

Technical Evaluation Report  
on the  
Flight Mechanics Panel Symposium  
on  
Flight in Adverse Environmental  
Conditions

NORTH ATLANTIC TREATY ORGANIZATION



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NORTH ATLANTIC TREATY ORGANIZATION  
 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT  
 (ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.277  
**TECHNICAL EVALUATION REPORT**  
 on the  
**FLIGHT MECHANICS PANEL SYMPOSIUM**  
 on  
**FLIGHT IN ADVERSE ENVIRONMENTAL CONDITIONS**  
 by

J.F.Renaudie  
 Project Certification Manager  
 Service Technique des Programmes Aéronautiques  
 26 Boulevard Victor  
 75996 Paris Armées  
 France



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- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
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Published October 1989

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ISBN 92-835-0531-X



*Printed by Specialised Printing Services Limited  
40 Chigwell Lane, Loughton, Essex IG10 3TZ*

## PREFACE

Although AGARD has continued to be active in the various fields of flight in adverse environmental conditions, the Flight Mechanics Panel considered it to be important and timely to review in 1989 the subject in a wider forum such as a symposium.

Four aspects of adverse environmental conditions of interest to the flight mechanics specialists would be addressed by such a symposium: atmospheric disturbances, reduced visibility, icing, and electromagnetic disturbances. All four of these can seriously affect flight safety, comfort, and operational capability.

The topic is considered to be particularly relevant to the needs of the military community which is putting increased emphasis on the ability of today's and tomorrow's aircraft to fly safely and effectively in the types of adverse conditions to be dealt with in this Symposium.

A symposium addressing these topics was held at Gol, Norway from 8—11 May 1989, and this report evaluates the extent to which the objectives of this meeting were met and gives recommendations for future activities in this area.

\* \* \*

L'AGARD n'a pas cessé de jouer un rôle actif dans le domaine du vol en conditions adverses; cependant la Commission de Mécanique du vol a jugé utile et opportun de faire, en Mai 1989, le point de la question, dans le cadre d'un symposium.

L'objectif de ce symposium devait être de traiter de quatre sujets intéressant le spécialiste de la mécanique du vol c'est-à-dire: les perturbations atmosphériques, la visibilité réduite, le givrage et les perturbations électromagnétiques. Chacun de ces quatre éléments peut en effet, avoir des répercussions importantes sur la sécurité du vol, le confort et la capacité opérationnelle de l'aéronef.

Ce sujet concerne la communauté militaire, qui voit là intérêt accru dans la capacité des avions actuels et futurs d'effectuer leurs missions efficacement et en meilleure sécurité.

Un symposium traitant de ces sujets a donc été organisé à Gol, Norvège, du 8 au 11 Mai 1989. Ce rapport résume les points forts de cette réunion, examine si les objectifs ont été atteints et conclue par des recommandations pour l'activité future dans ce domaine.

# **TECHNICAL PROGRAMME COMMITTEE**

Dr B.W.McCormick  
Department of Aerospace Engineering  
Pennsylvania State University  
233 Hammond Building  
University Park  
PA 16802  
USA

Prof. Dr-Ing. G.Schaenzer  
Director of Institute of Guidance and Control  
Technical University Braunschweig  
Hans-Sommer-Str. 66  
D-3300 Braunschweig

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## 1 - HIGHLIGHTS OF THE SYMPOSIUM

The full proceedings of this symposium are published under the number AGARD-CP-470, however, for the reader of this Technical Evaluation Report it may be usefull to direct his attention to the best papers provided during the symposium, and to invite him, if too short of time to read in totallity the proceedingss, to devote nevertheless some attention to those papers which may be selected as the best ones according to the interest of the audience and the judgment of the Technical Evaluation Reporter. These are the following :

(with corresponding reference numbers)

- (3) Analysis of Severe Atmospheric Disturbances from Airline Flight Records  
R.C. WINGROVE, R.E.BACH, Jr, & T.A. SCHULTZ, NASA Ames, Moffett Field, US
- (7) Influence of Wind Shear, Downdraft and Turbulence on Flight Safety  
G. SCHAEENZER, Technical University, Braunschweig, GE
- (9) Cisaillement du Vent et Commandes de Vol Electriques  
(Wind Shear and Fly-by-Wire)  
J-L. BONAFE, Aerospatiale, FR
- (14) The Interference of Flightmechanical Control Laws with those of Gust Load Alleviation and its Influence on Structural Design  
R. MOBEST & M. MOLZOW, MBB GmbH, Hamburg, GE
- (22) NASA's Program on Icing Research and Technology  
J.J. REINMANN, R.J. SHAW & R.J. RANAUDO, NASA Lewis Research Center, Cleveland, US
- (26) Effects of Lightning on Operations of Aerospace Vehicles  
B.D. FISHER, NASA Langley Research Center, Virginia, US
- (28) EMC Flight Testing  
P. NEWTON, A&AEE, Boscombe Down, UK
- (29) Principales Caractéristiques des Foudrolements sur Avions  
(Main Characteristics of Lightning Strikes on Aircraft)  
J-L. BOULAY, ONERA, FR

In addition the great interest of the Discussion Session with the Royal Norwegian Air Force pilots may be pointed out.

This discussion was reported by J.F. RENAUDIE (STPA FRANCE), and included in the proceedings of the Symposium.

## 2. BACKGROUND AND OBJECTIVES

2.0 - It has been found suitable to use the Pilot Paper written by the Technical Programme Committee for that meeting, since it outlines the background and aims of the meeting as agreed by the Flight Mechanics Panel. Therefore this Pilot Paper is included in paragraph 2.1 and 2.2 below, with minor editorial changes. The Technical Evaluation Reporter expresses his thanks to Professor SCHAEENZER and Mr. Mc CORMICK for having agreed that.

## 2.1 - Background

Adverse environmental conditions have four manifestations of primary interest to the Flight Mechanics Specialists : atmospheric disturbances, visibility, icing, and electromagnetic disturbances. All four manifestations can seriously influence flight safety, comfort, and operational capabilities.

The Flight Mechanics Panel (FMP) has an ongoing subgroup on the topic of wind shear. In addition, the panel has sponsored two working groups on the topic of Rotorcraft Icing. The last symposium was a FMP Symposium, " Flight in Turbulence ", Bedford, UK in 1982.

Since that time there have been many activities relative to fixed-wing aircraft concerns, e.g. JAWS, Low CAT, Wake Vortex Measurement, wind shear measurement and investigations, flow field and turbulence measurements around geographic obstacles which have produced important results and could be usefully assessed.

Additional advances have been made in design of active control systems which can provide significant alleviation of gust loads and turbulence response ; the immense growth of electronic devices in the aircraft will improve handling qualities and flight safety, e.g. fly by wire, CCV. These electrically signalled control systems and installed equipment can be significantly effected by electromagnetic disturbances, especially in flights at greater altitudes.

The increased emphasis by the military on being able to operate in poor weather and at night has resulted in the development of vision aids such as light intensification and infrared devices. These developments have been applied to fixed-wing aircraft and helicopters and now allow operations close to the ground in poor visibility and more adverse weather conditions. The problem has therefore expanded and there is increased need not only to make the aircraft resistant to the adverse conditions but also improve the ability to model and predict these adverse conditions so that the built-in capabilities are not exceeded.

## 2.2 - Objectives

The objectives of the meeting were as follows :

The symposium was to be structured around five sessions totalling about thirty papers with a round-table discussion as the wrap-up.

### **Session 1 - Atmospheric Measurements and Modeling (6 papers)**

Measurement modeling and prediction of phenomena such as very low and slow turbulence models for helicopters, measuring modeling and prediction of wind shear around ground objects, downdrafts, specific phenomena such as thunderstorms, including lightning, wake turbulence, etc ...

### **Session 2 - Effects of Disturbances on Design and operation (12 papers)**

Design consequences. The effect on vehicle design of various atmospheric disturbances including the structure, control system, sensors, and instrumentation.

Operational consequences. Prediction and forecasting of adverse conditions and the definition of the degraded operational capabilities and training requirement and devices

### **Session 3 - Visibility (3 Papers)**

This would cover the general subject of poor visibility due to weather and darkness. Topics to be discussed include prediction, modeling, simulation, definition of operational limitations, training requirements and devices, and the design consequences of additional systems required. Operational conditions of interest include take-off and landing, very low altitude penetration and ground attack for fixed-wing aircraft, and low altitude nap-of-the-earth (NOE) operation for helicopters.

### **Session 4 - Icing (4 Papers)**

Icing conditions for helicopters, aircraft and the runways. This includes modeling atmospheres, forecasting, the effects on operational capabilities, modeling the phenomena, and design consequences such as anti-icing and de-icing equipment.

### **Session 5 - Electromagnetic Disturbances**

Effects of electromagnetic disturbances on electronic devices critical to flight. This includes description of the response of such components to electromagnetic disturbances, the occurrence of the electromagnetic disturbances, the effect on flight safety and procedures for protection.

## **3. TECHNICAL EVALUATION**

### **3.0 - Structure and Programme achieved**

The list of presentations giving the full title and authors of each Paper, with reference number is given in Appendix 1.

From the 29 papers registered, 3 were cancelled. It may be pointed out that there was no round table at the end of the meeting, but it was replaced by a very interesting discussion between the participants, and members of the Norwegian Air Force.

Owing to the great interest of this discussion it was decided by the Technical Programme Committee, to include the report of this discussion, as prepared by J.F. RENAUDIE STPA/France, in the Proceedings of the Symposium.

In this technical evaluation the papers are designated by their reference number.

### **3.1 - Session I - Atmospheric measurements and Modelling**

- 3.1.1 - Apart from paper (6) from C. TOMKINS which gives a broad picture of all atmospheric measurements and experiments including ground facilities, in relation with adverse atmospheric events, such as extremes of temperature, storm, icing, lightning, electromagnetic interferences, clouds, visibility and air pollution, all other papers deal with measurements of wind velocity vector (with component along all three earth axes, including speed vector rotations).

Special mention of paper (3) from NASA, Ames, must be made because it addresses both subjects of, Session I and III (See later comments, in paragraph 3.2)

- 3.1.2 - Paper (4) describes the challenge of these kinds of measurements of very small wind speed vector values as differences between the airspeed and ground speed vectors of the aircraft. This is obviously the origin of all problems found, in the technique of atmospheric measurements.
- 3.1.3 - From all these papers, only one, paper (5) was expected to address high altitude atmosphere up to 20 km, unfortunately this paper was withdrawn. Generally all the papers deal mainly with transport aircraft, and one of the major sources of knowledge is that provided by data recording (now generally digital) made in airline operations (papers (1), (2), (3)).
- 3.1.4 - Nevertheless the need of test aircraft with specific flight test installation, at least to provide a method for deriving the atmospheric wind measurements from airline recording, is pointed out by four papers (1), (2), (4), (5) and examples chosen are transport aircraft (Nord 262, Dornier 128 and 228).
- 3.1.5 - A variety of means are used to provide accurate derivation of wind vectors ; nevertheless none of the papers mention the laser flow measurements which were sometime used in the past ; only paper (5) which was cancelled, was expected to address the classical use of meteorological balloons with telemetry. All papers insist on the need of good aircraft position recordings by on board means (inertial reference system, or satellite positioning system) and check of position by ground radar positioning (ATC radars) ; this is specifically mentioned when the purpose is to investigate whether the origin of an airline incident/accident is an atmospheric event, or not.
- 3.1.6 - Energy height and its rate of change are mentioned as the most sensitive parameters to provide windshear evidence.

### 3.2 Session II Effects of disturbances on design and operations

#### 3.2.0 - Overview of the session :

While paper (12) gives a picture of a number of atmospheric events encountered during the Canadian Atlantic Storm Programme (CASP), such as icing, snow encounter with poor visibility, high wind shears and crosswinds, six of the papers presented address the major subject of wind shear effects on aircraft (papers (7), (8), (9), (11), (13)).

Some papers address more specifically the following atmospheric events, or type of operations

- gusts : paper (14), (13), (7)
- flight conditions at low level, for low level high speed (13)
- helicopter operations (18)
- vortex wake encounter (17)

The evaluation of this session will be made under the three following headings :

- overall picture of atmospheric events (parag. 3.2.1)
- operations in adverse weather (parag. 3.2.2)
- design of aircraft for bad weather (parag. 3.2.3)
- experimental programmes and studies (parag. 3.2.4)

### 3.2.1 - Overall picture of some atmospheric events

The Canadian Atlantic Storm Programme presentation made in paper (12) could have been part of session I, since it describes the penetration of storm with a specifically equipped aircraft, (31 flights) made on a modified TWIN OTTER, carrying a specific instrumentation system ; therefore it is indirectly linked to the title of session II ; its interest is to present the means needed to complete such a flight test campaign :

- the test aircraft itself, TWIN OTTER, specially modified to survive a penetration into severe icing environment for a long time, and equipped with instrumentation needed for water droplet size measurements, cloud water concentration, in addition to the usual flight parameters.
- a second aircraft (DC3) able to divert to alternate airfields at greater distances than the TWIN OTTER.
- 3 weather Radars, meteorological towers, buoys, ships.
- satellite navigation.

In spite of the great interest, in presenting an experience of penetration into very bad atmospheric conditions, this paper does not give all the lessons which could be extracted from this experiment to the design of new aircraft, or in the operation of them in bad weather. These two subjects are covered at different depths by the other papers, as explained in the following paragraphs.

### 3.2.2 - Operations in adverse weather

Four main concerns are addressed

- in flight detection of events
- aircraft trajectory
- crew reactions and correct crew procedure
- specific case of short/vertical take off aircraft and helicopters.

(a) in flight detection of events, addresses mainly wind shear detection. All authors of papers (7), (8), (9) agree on the finding that the best parameter for detection is based on energy height (which expresses the sum of potential and kinetic energy of the vehicle). Difference between energy height, actual and expected and their rate of variation, gives a way to introduce some phase advance, needed for proper crew reaction, and provide the input of warning displays. Nevertheless the usefulness of point source sensors is found very limited by A.E. WOODFIELD in paper (8) who concludes his written paper :

" Point source sensors cannot produce information on the total size of a windshear until after it has occurred. This is too late to help a pilot. "

Cathode tube flight instruments, are probably those which provide the best flexibility to introduce such warnings, using pointers giving the energy height, and its rate of change.

(b) Aircraft trajectory : example of trajectory is given by paper (3) F. WINGROVE, with illustration of a video film explaining the accident of flight Delta 191, in Aug 1985 at Denver.

(c) Crew reactions and procedure : are addressed by three papers (3), (7), (9), only to state that the right crew procedure has to be found within the existing limitations of the aircraft, in terms of low speed, stall, etc ... which is not easy unless the aircraft is fully protected (see below parag. 3.2.4). The video film on Delta 191 accident used to illustrate paper (3) explains that the right crew reaction is against the instinct of the pilot to maintain the airspeed. It suggests that the lesson for airline pilots is the following :

- 1) avoid downburst if you can
- 2) if you are in a down burst :
  - pull up, attitude 15°
  - full throttle
  - forget all previous experience.

All specialists agree on the need to avoid building up the rate of descent, even at the cost of a very low speed, close to stall.

(d) The specific case of CTOL/VTOL and helicopters is addressed in Paper (18) ; attention is driven toward the scale of atmospheric events which is useful to consider for those vehicles which can hover and at least for helicopters, have rotors which performance/behaviour can be disturbed by air motion fields characterized by the same dimensions as the rotors. This is in particular the case of Rotating Frame Turbulence (RFT) which is often produced by relatively small obstacles on the ground (buildings, bridges, hills, cliffs etc ...) in the air stream close to ground surface.

The Technical Evaluation Reporter believes that the Author of this interesting paper should be encouraged to pursue this work, and in particular be helped to validate it by flight testing. This RFT could be as important for helicopters as is the microburst for aircraft.

### 3.2.3 - Design of aircraft for better behaviour in adverse weather

The papers presented address mainly the behaviour in adverse 3D wind velocity situations, and means to improve safety and passengers comfort, reduce structural loads, make easier crew reactions. Paper (14) gives a description of the gust load alleviation system implemented on the transport aircraft A320, to save structural weight, thanks to reduction of wing flexure loads, and addresses the failure cases of the system.

Paper (9) takes the example of the same Airbus A320 implementing in its systems the following protections :

- stall protection : which enables the pilot to pitch up the aircraft up to maximum lift, without any risk of excursions to higher angles of attack, and therefore stall the aircraft.
- automatic triggering of full thrust when speed decreases below a minimum value
- automatic limitations of load factor above 2.5 g and, overspeed above VMO/MO.

These protections, in particular the two first ones appear as the major weapon of the pilots against strong windshears, since it enables one to fully apply the procedures pointed out by paper (3)

(See above parag. 3.2.2 c) without worrying about the stall.

With this system implemented the crew procedure in case of windshear alarm is the following :

- . in case of windshear at take off = follow the Flight Director
- . in case of windshear at landing = do not alter gear flap positions, and go around with maximum thrust.

### 3.2.4 - Experimental programmes, or studies

Paper (13) presents the principle of "antiroughride" system for level flight at low level, high speed, based on a loop in the flight control system, detecting the difference between the incidence derived from the inertial reference system, and that derived from the incidence vanes. Comparison is made by computation between canard, and aft tail configurations.

(Paper 16) presents the experimental DORNIER 28 TNT implementing the OLGA system to improve passenger comfort while flying through gusts. It presents a very interesting analysis of frequency response of aircraft structure, and human body.

- 3.2.5 - In summary : this session covers quite adequately the intent of its title, taking into account that other factors such as low visibility, icing, electromagnetic interferences are dealt with in sessions. III, IV, V.

### 3.3. Session III - Visibility

- 3.3.1 - It may be recalled that the objectives of this session was the following, as stated in the pilot paper :

Quotation :

This would cover the general subject of poor visibility due to weather and darkness. Topics to be discussed include prediction, modeling, simulation, definition of operational limitations, training requirements and devices, and the design consequences of additional systems required. Operational conditions of interest include take-off and landing, very low altitude penetration and ground attack for fixed-wing aircraft, and low altitude nap-of-the-earth NOE operation for helicopters.

end of quotation.

This subject was only partially covered, with only three papers, summarized as follows :

- Paper (19) addresses the correlation between spot meteorological measurements and overall meteorological situations over an extended area in the North of Germany. Well presented, and interesting, it has nevertheless very small relation with the subject of this symposium, which addresses either the measurement/assessment of poor visibility, or the way to overcome the corresponding problem, i.e. how to fly in poor visibility.
- Paper (21) which was scheduled to address the use of ground based forward looking infrared systems to provide tactical precision approach systems was cancelled and replaced by a paper on new means for measurement of visibility, based on contrast measurements.
- Paper (20) is much more interesting because it points out the real need, when flying helicopters at low altitude, of a proper interface, between man, and outside world. It points out that in addition to the usual sensors providing adequate viewing of the horizon in the direction of the flight (flight vector), the sensors used must provide at least a good coverage of the field of view below the helicopter as an essential complement.  
The optimum should be to get a coverage of the total field of view around the vehicle with higher accuracy, magnification, in the two following specific areas :
  - . around the speed vector,
  - . around the vertical axis of the vehicle (downward).

3.3.2 - The gaps in this session may be summarized saying that the following factors producing poor visibility are not covered :

- in weather flying, including clouds and precipitations, rain, drizzle, fog)
- smoke, smog (solid particles such as those above a ground battlefield, or above industrial factories, and mixed with clouds)
- sand storms

Therefore no answers are given in this symposium to these problems.

Nevertheless this question has already been studied within AGARD and the following comments may be extracted from the unclassified part of conclusions of AGARD Aerospace Application Study N° 19 on " All weather capability of combat aircraft " (Note) :

- a) confirmation is given of the very specific use of all infra-red sensor systems for dry air nights. The range reduction is such that it cannot be seriously envisaged to use them for precise tasks in weather such as take off and landing.

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Note AAS 19 study on all weather operations of combat aircraft, was a study sponsored by the Aerospace Application Standing Committee of AGARD, and directed by J.F. RENAUDIE (France).

b) electromagnetic systems are far more promising ; the key factor is the wavelength, compared to the dimensions of particles, diameter of water droplets, or ice crystal. It is feasible to select the right wavelength for optimum transmission ; best transmissions are given for VHF frequencies ; millimetric wave radars provide quasi optical picture definition while having a range far better than present Infra-red systems, but still not sufficient in spite of the progress made.

For navigation only, when the image of the target or obstacle is not required, widely used ATC Radar systems, operating on longer wavelength are satisfactory. New positioning systems of very high accuracy, such as the NAVSTAR Global Positioning System, operating from a set of earth satellites, or local radio electrical system having the same frequency, but operating from a set of ground stations, such as the TRIDENT (THOMSON) are very promising to provide new navigation aids used in all flight phases, including take off and landing.

For all these electromagnetic systems stealthiness remains a problem.

### 3.4. Session IV - Icing

#### 3.4.1 - Icing research and technology

In this session paper (22) on NASA's programme on Icing Research and technology meets the challenge of providing in 22 pages a very extensive presentation of almost all subjects related to icing. It would be unfair to the Authors to present in a few lines a summary of such a rich and interesting paper, and the following remarks are made only to invite the reader of this report to read completely this interesting paper as complemented by papers (23) and (24).

##### (a) Physical mechanism of icing

it involves a number of parameters : airspeed, outside air temperature, altitude, cloud liquid water content or concentration, cloud droplet size distribution, size or scale of model or aircraft exposed to icing - Mach and Reynolds numbers, etc ...

Ice formed in flight over the aircraft skin results from supercooled water droplets impacting the airframe surface at the flight speed.

A number of types of ice may result from variations of the above parameters, mainly liquid water concentration and droplet size distribution in clouds. Adhesion on the skin depends on the type of icing, and roughness of surface. Basic mechanical properties of ice accreted is (1) tensile (Young's Modules) (2) Shear (adhesion) (3) peeling properties.

##### (b) Protection against icing

With the decrease of available hot air bleed of new fan engine there is a need to develop new deicing systems using less bleed, or more efficiently, or newer systems relying on other sources of energy.

New systems are being developed based on electrical capacitor discharge, using external boots on the surfaces to protect, such as Electro-Expulsive Separation System, or Eddy Current Repulsion Deicing Boot, or installed inside the airframe, such as the Electromagnetic Impulse Deicer. All these systems provide very short duration impulses, but high forces, and have been found very efficient. Ground deicing fluids are also presented in detail in paper (22) while testing of these fluids is the main subject of paper (24).

(c) Computation of icing accretion aircraft performance degradation

Prediction of airfoil aerodynamic performance degradation due to icing is now made possible with the high capacity computers of to-day. The code of the method used at NASA LEWIS is named LEWICE. It uses inviscid flow equations, and determines the freezing point, by solving continuity and energy equations in each control volume of the flow.

Comparisons with experiment give confidence in this code at least for the low incidences ; the Authors state that viscous-fluid equations will have to be used for better consistency with experiments at higher angle of attacks close to CL max.

(d) Icing testing

The main ground testing means mentioned is the NASA LEWIS Icing Research wind tunnel which is the largest refrigerated tunnel in the world capable of testing big models of aircraft, helicopters, wing profiles etc ...

Flight test research is conducted at NASA LEWIS using a modified TWIN OTTER implementing modified basic deicing systems. Wings and gear struts are used to flight test ice accretion and new deicing systems.

Measurements associated with this kind of testing involve a number of devices such as :

- forward scattering spectrometer probe
  - optical array probe
  - phase doppler particle analyser
- to measure the dimensions of water particles

- (e) Ice induced degradation of performance of helicopter is shown in Paper (23) while paper (24) describes the flight testing and wind tunnel investigation of aerodynamic effects of aircraft ground De/Anti/Icing fluids. It may be mentioned that use of these fluids may downgrade the lift performance of the Aircraft by about 10 % depending on the wing surface.

### 3.4.2 - Icing operational experience

A number of known airline incidents or accidents are due to icing (Tail icing, propeller and engine icing).

With the exception of paper (12) of session II, on the Canadian Storm project (See above parag. 3.2.1) this subject is not addressed, and this may be found regrettable. The only paper addressing partly this subject was that expected from D.R. ELLIS of KANSAS University (US), on problems due to ice accretion on the tail of a twin engine aircraft. Unfortunately this presentation was cancelled.

### 3.5. Session V - Electromagnetic Interferences

3.5.1 - This session includes 3 papers, each of them bringing complementary information to the others. The following items are worthwhile mentioning :

(a) Paper (26) points out that, surprisingly, severe lightning strikes can be found where one would not expect it :

- . Aircraft lightning strikes occur in both thunderstorm and non thunderstorm conditions.
- . The thunderstorms regions with the highest probability for an aircraft to experience a direct lightning strike were those areas where the ambient temperature was  $-40^{\circ}\text{C}$ , where the relative turbulence and precipitation intensities were characterized as negligible to light, and where the lightning flash rate was less than 10 flashes/min. However, direct lightning strikes were encountered at nearly all temperatures and altitudes.
- . The non-thunderstorm regions with the highest probability for an aircraft to experience a direct lightning strike were those areas where the ambient temperature was between  $\pm 10^{\circ}\text{C}$ , in rain, where the relative turbulence intensity was characterized as negligible to light, and where there was little or no other lightning activity.
- . Most aircraft lightning strikes are triggered by the vehicle itself. Lightning strikes in which the aircraft intercepts a naturally-occurring lightning flash also occur, predominantly at lower altitudes.
- . The presence and location of lightning do not necessarily indicate the presence or location of hazardous precipitation and turbulence. In addition, hazardous precipitation and turbulence are not necessarily related to one another.

(b) Paper (28) gives a detailed explanation of the mechanism of Electromagnetic interferences, and corresponding threats, based on resonance and coupling factors, and an up to date description of flight test and ground test methods.

(c) Paper (29) gives a description of the main characteristics of lightning strike on an aircraft ...

3.5.2 - The coverage of the subject of this session is found adequate, with the complementary information given during the discussion period of definition of typical EMI threat and lightning threats, which are already used, for certification of new transport aircraft, such as the Airbus A320 (according to European Joint Airworthiness requirements) These requirements are included as Appendix 2 and 3 to this T.E.R.

#### 4. CONCLUSIONS AND RECOMMENDATIONS

##### 4.1. Conclusions

The objectives of the programme organizers were achieved, though to a lesser extent than was hoped. As in previous meetings of this type, the balance between adverse weather conditions due to wind shear, gusts, turbulence on the one hand, and other adverse conditions, such as flying in weather, tended to favor the former.

Nevertheless this is the first time when specific full sessions were devoted to visibility, icing, electromagnetic interferences. This means that progress has been made towards a better coverage of the subject of adverse flying conditions.

The following comments may be made on each session :

- In session I, while a majority of papers address wind velocity measurements, there is very little information, sometimes no information at all on the following subjects :
  - high atmosphere (addressed by only one paper)
  - modeling effects of obstacles (large, such as mountain rifts, small as buildings, or installations on the deck of a carrier ship).
  - sand storms.
- In session II devoted to design and operations similar gaps may be noted ; there is nothing said on
  - . rough airfield operations,
  - . high altitude airfield with low air density
  - . take off/ landing from a carrier ship
  - . microburst, windshear detection by ground based installations
  - . flight through heavy precipitations - water ingestion by propulsion systems.
- Session III Visibility is the weakest of all these sessions : Only night flying is addressed and then only in one paper out of three ; the two remaining papers describe meteorological measurements and equipment.  
 There is nothing about flying IFR, or through clouds, smoke or other pollution. In addition this session is strongly unbalanced, since it addresses only the infra-red sensors to cope with the visibility problem ; clearly all the powerful electromagnetic means on ground, or on board which have been developed to fly in weather have not been dealt with.  
 There is a large amount of work developed by civil and military aviation specialists, to improve operations in adverse weather. Civil transport aircraft land now routinely with the most adverse conditions of Cat III-Military services have developed means to set up on unprepared airfield devices able to let fighter or transport aircraft take off and land in adverse weather. Some of this material is classified, and therefore this could be one of the reasons not to have been able to address it in this symposium.

In session IV on icing the paper of exceptional quality given by the specialists of NASA-LEWIS is worthwhile mentioning ; it covers almost the totality of the subject.

In session V, on Electro Magnetic Interferences (EMI) and lightning strike there were three excellent and complementary papers and during this discussion the EMI and lightning Strike Threat definition used by the Joint European Airworthiness Authorities for Certification of Transport aircraft, was distributed as an appendix to the papers. The coverage of the subject was excellent.

In conclusion :

- The papers were generally excellent, some of them of outstanding quality. Audience participation was intense at times, and the several areas where further activity is requested were well identified.
- As an interdisciplinary type symposium, it would seem to have been quite successful in bringing together, as it did, specialists of so many different discipline, and opening a fruitful discussion with operational crews of the Royal Norwegian Air Force.
- A successful turn has been taken to reorientate the programme of such meetings in order to get a better balance between adverse conditions originated by wind velocities, and those originated by other sources.

4.2. Recommendations

It is suggested that the FMP could set up a follow up meeting, Multi Panel Symposium, which would extend the subject to flight in hostile/adverse environment, for military operations. It would be a classified meeting, with high participation of military operators ; three main sessions are suggested :

- A. Adverse environment
- B. Operational problems
- C. Hostile environment.

The contents of each session would be as follows :

Session A - Adverse environment

- Wind velocity . 1 paper giving the summary of sessions 1 and 2 of the GOL meeting, with proper updating and one paper for each following subject :
  - icing
  - electromagnetic interferences
  - precipitations : liquid/water, snow, and storms
  - Flight in adverse weather:summary of AGARD Aerospace Application Study AAS 19 on all weather capability of combat aircraft
 The coverage of this last subject would be extended with several updating papers in order to address the progress made since AAS 19.

Session B - Operational problems

- a) Operations from
  - unprepared surfaces
  - high altitude airfield
  - rough airfield
  - water surface (sea planes)
  - Carrier ships
- b) emergency situations
  - crash
  - ditching

Session C. Hostile environment

- Design for stealthness - Balance between stealthness and performances
- Flight with damaged aerodynamic surfaces, following combat
- Flight control integrity in combat environment
- Escape systems

These sessions would be closed by a round table with participation of military operational specialists.

It is hoped that the Flight Mechanics Panel of AGARD will agree to arrange at a convenient date such a classified symposium on

Flight in adverse and hostile conditions.

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**APPENDIX 1**  
**LIST OF PRESENTATIONS**

MILITARY KEYNOTE SPEAKER Mr B. CHILDS, UK  
 CIVIL KEYNOTE SPEAKER - Mr J-H. ENDERS, US

**SESSION I - ATMOSPHERIC MEASUREMENTS AND MODELING**

Chairmen : D. KEY (US) and J. ABBINK (NE)

- (1) Description de la Turbulence Atmosphérique  
 (Description of Atmospheric Turbulence)  
 P-M. HUTIN, ONERA, FR
- (2) Wind Shear Models for Aircraft Hazard Investigation  
 M. SWOLINSKY, Technical University, Braunschweig, GE
- (3) Analysis of Severe Atmospheric Disturbances from Airline Flight Records  
 R.C. WINGROVE, R.E. BACH, Jr, & T.A. SCHULTZ, NASA Ames, Moffett Field, US
- (4) Systems for Airborne Wind and Turbulence Measurement  
 P. VORSMANN, Aerodata Flugmesstechnik GmbH, GE
- (5) Cancelled.
- (6) USAF Testing Under Extreme Environmental Conditions  
 C. TOMKINS, AFMTC, Edwards AFB, US

**SESSION II - EFFECTS OF DISTURBANCES ON DESIGN AND OPERATION**

Chairman : H. WUNNENBERG (GE) and M-H. FOCHE (FR)

- (7) Influence of Wind Shear, Downdraft and Turbulence on Flight Safety  
 G. SCHAEZNER, Technical University, Braunschweig, GE
- (8) General Classification of Wind Shear Severity  
 A.A. WOODFIELD, R.A.E. Bedford, UK
- (9) Cisaillement du Vent et Commandes de Vol Electriques  
 (Wind Shear and Fly-by-Wire)  
 J-L. BONAFAE Aerospatiale, FR
- (10) Cancelled
- (11) A Pitch Control Law for Compensation of the Phugoid Mode induced by  
 Windshears  
 L.M.B.C. CAMPOS, Insitituto Superior, Lisbon, PO
- (12) Adverse Weather Operations during the Canadian Atlantic Storms Project  
 J.I. MACPHERSON & G.A. ISAAC, National Research Council, CA

- (13) Ride Control Systems Design Methodology - Canard Versus Tail  
L. MANGIACASALE & L.V. CIOFFI, Aermacchi, Varese, IT
- (14) The Interference of Flightmechanical Control Laws with those of Gust Load Alleviation and its Influence on Structural Design  
R. MOBEST & M. MOLZOW, MBB GmbH, Hamburg, GE
- (15) Gust Velocity Effects on CTOL and VTOL Aircraft Flight Dynamics and Control  
R.L. SWAIM, Oklahoma State University, US
- (16) Active Control System for Gust Load Alleviation and Structural Damping  
H. BOEHRET & J. WINTER, Dornier GmbH, GE
- (17) Aircraft Response and Pilot Behaviour during a Wake Vortex Encounter Perpendicular to the Vortex Axis  
R. KOENIG, DFVLR, Braunschweig, GE
- (18) Effects of Rotating Frame Turbulence on Helicopter Flight Mechanics  
D.P. SCHRAGE IVR PRASAD & G.H. GAONKAR, Georgia Institute of Technology, US

### SESSION III - VISIBILITY

Chairmen : L. REID (CA) and G. SACHS (GE)

- (19) Measurement of Horizontal Visibility in the Lowest 300m over Northern Germany  
R. ROTH & A. SIEMER, University of Hannover, GE
- (20) Imaging Probabilities, Geometry and Ergonomics in Limited Visibility Helicopter Operations  
R.H. WRIGHT, US Army Research Inst. , Alabama, US
- (21) The Use of Ground Based FLIR to Provide Tactical Precision Aircraft Approach System  
A.W. PUFFET, R.A.E. Bedford, UK

### SESSION IV - ICING

Chairmen : C.E. ADOLPH (US) and P.R. SULLY (CA)

- (22) NASA's Program on Icing Research and Technology  
J.J. REINMANN, R.J. SHAW & R.J. RANAUDO, NASA Lewis Research Center, Cleveland, US
- (23) Ice Induced Aerodynamic Performance Degradation of Rotorcraft - An Overview  
K.D. KORKAN & R.K. BRITTON, Texas A & M University, US
- (24) Results of a Flight and Wind Tunnel Investigation of Aerodynamic Effects of Aircraft Ground De-Anti-Icing Fluids  
E.G. HILL, T.A. ZIERTON & L.J. RUNYAN, The Boeing Company, Seattle, US
- (25) Cancelled

**SESSION V - ELECTROMAGNETIC INTERFERENCES**

Chairmen : R. HILDEBRAND (US) and A. WOODFIELD (UK)

(26) Effects of lightning on Operations of Aerospace Vehicles  
B.D. FISHER, NASA Langley Research Center, Virginia, US

(27) Cancelled

(28) EMC Flight Testing  
P. NEWTON, A & AEE, Boscombe Down, UK

(29) Principales Caractéristiques des Foudroiements sur Avions  
(Main Characteristics of Lightning Strikes on Aircraft)  
J-L. BOULAY, ONERA, FR

**DISCUSSION SESSION WITH THE ROYAL NORWEGIAN AIR FORCE**

(this discussion took place at the end of Session IV)

APPENDIX 2

## JOINT EUROPEAN AIRWORTHINESS - REQUIREMENTS - EXTERNAL RADIATION THREAT

SYSTEMSReferences:

1. CRI SE 2001
2. JAR 25.1309 (a) and (b)
- JAR 25.1431 (a)
- SC - S76

## INTERPRETATIVE MATERIAL

IM - S76

Status : CLOSED

Date : 10.07.87.

EFFECT OF EXTERNAL RADIATIONS  
UPON AIRCRAFT SYSTEMS

The external threat frequency bands and corresponding average and peak levels that shall be used to establish the internal threat levels are defined as follows:

<u>EXTERNAL THREAT</u>		
<u>FREQUENCY RANGE</u>	<u>LEVEL</u>	
	<u>MEAN</u>	<u>PEAK</u>
	Volt/meter	kilovolt/meter
10 kiloHertz - 6 MegaHertz	100	-
6 MegaHertz - 30 MegaHertz	200	-
30 MegaHertz - 200 MegaHertz	50	-
200 MegaHertz - 400 MegaHertz	50	-
400 MegaHertz - 1 GigaHertz	400	6
1 GigaHertz - 3 GigaHertz	200	6
3 GigaHertz - 8 GigaHertz	400	6
8 GigaHertz - 20 GigaHertz	600	6

Note: The detailed means of establishing compliance for each system, will need to be agreed with the AA.

APPENDIX 3JOINT EUROPEAN AIRWORTHINESS - REQUIREMENTS  
LIGHTNING THREATReferences:

1. CRI SE 2004
2. JAR 25.581  
25X899  
25.1309  
25.1431  
SC S75

INTERPRETATIVE MATERIAL

IM - S75  
Status : Closed  
Date : 20.08.87.

LIGHTNING PROTECTION INDIRECT EFFECTS

The lightning strike models to be used for system justification shall be as follows:-

SEVERE STRIKE (FIRST RETURN STROKE)

Peak Amplitude - 200 Kilo Amp.  
Peak Rate of Rise 200 Kilo Amp./microsecond  
Action Integral  $2 \times 10^6 \text{ Amp}^2 - \text{sec}$   
Bi-exponential waveshape.

MULTIPLE STROKE FLASH (CLOUD TO GROUND STRIKES)

The model shall consist of 24 strokes randomly distributed within 2 seconds, with the following characteristics:

First Stroke - Peak Amplitude, 200 Kilo Amp.  
Peak Rate of Rise, 140 KA/microsecond  
Action Integral,  $2 \times 10^6 \text{ Amp}^2.\text{sec}$   
23 Strokes - Peak Amplitude, 50 Kilo Amp.  
Peak Rate of Rise, 70KA/microsecond  
Action Integral, each  $0.0625 \times 10^6 \text{ Amp}^2.\text{sec}$

MULTIPLE BURST (CLOUD TO CLOUD STRIKES)

The model shall consist of 24 sets of 20 strokes randomly distributed within 2 seconds, with the following characteristics:

Peak Amplitude - 10 Kilo Amp.  
Peak Rate of Rise - 200 Kilo Amp./microsecond

NOTE:

While the detailed M.O.C. will need to be agreed with the AA, taking into account the effect on the aircraft, it should be noted that :

- (i) Any combination of analysis and testing should be negotiated with the AA.
- (ii) For test results an extrapolation of the threat current parameters of more than a factor of 10 is not likely to be acceptable without an additional safety factor being applied.
- (iii) For a proven analysis technique, a safety factor of at least 2 will be required.

REPORT DOCUMENTATION PAGE			
1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-277	ISBN 92-835-0531-X	UNCLASSIFIED
5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France		
6. Title	TECHNICAL EVALUATION REPORT ON THE FLIGHT MECHANICS PANEL SYMPOSIUM ON FLIGHT IN ADVERSE ENVIRONMENTAL CONDITIONS		
7. Presented at			
8. Author(s)/Editor(s)	J.F.Renaudie		9. Date
			October 1989
10. Author's/Editor's Address	See Flyleaf.		11. Pages
			26
12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.		
13. Keywords/Descriptors	<div style="display: flex; justify-content: space-between;"> <div> All weather aviation Atmospheric disturbances Visibility </div> <div> Ice formation Electromagnetic environments Military aircraft </div> </div>		
14. Abstract	<p>In May 1989 the Flight Mechanics Panel of AGARD organised a Symposium on Flight in Adverse Environmental Conditions (the Conference Proceedings of this Symposium are published as AGARD CP 470).</p> <p>Four aspects of adverse environmental conditions of interest to the flight mechanics specialists were addressed by this symposium: atmospheric disturbances, reduced visibility, icing and electromagnetic disturbances. All four of these can seriously affect flight safety, comfort and operational capability.</p> <p>The topic was and still is considered to be particularly relevant to the needs of the military community which is putting increased emphasis on the ability of today's and tomorrow's aircraft to fly safely and effectively in the types of adverse conditions dealt with in this symposium.</p> <p>This Advisory Report has been prepared at the request of the Flight Mechanics Panel to evaluate the extent to which the objectives of the symposium were met, and to make recommendations for future activities in this area.</p>		

<p>AGARD Advisory Report No.277 Advisory Group for Aerospace Research and Development, NATO</p> <p>TECHNICAL EVALUATION REPORT ON THE FLIGHT MECHANICS PANEL SYMPOSIUM ON FLIGHT IN ADVERSE ENVIRONMENTAL CONDITIONS</p> <p>J.F.Renaudie Published October 1989 26 pages</p> <p>In May 1989 the Flight Mechanics Panel of AGARD organised a Symposium on Flight in Adverse Environmental Conditions (the Conference Proceedings of this Symposium are published as AGARD CP 470).</p> <p>P.T.O.</p>	<p>AGARD-AR-277</p> <p>All weather aviation Atmospheric disturbances Visibility Ice formation Electromagnetic environments Military aircraft</p>	<p>AGARD Advisory Report No.277 Advisory Group for Aerospace Research and Development, NATO</p> <p>TECHNICAL EVALUATION REPORT ON THE FLIGHT MECHANICS PANEL SYMPOSIUM ON FLIGHT IN ADVERSE ENVIRONMENTAL CONDITIONS</p> <p>J.F.Renaudie Published October 1989 26 pages</p> <p>In May 1989 the Flight Mechanics Panel of AGARD organised a Symposium on Flight in Adverse Environmental Conditions (the Conference Proceedings of this Symposium are published as AGARD CP 470).</p> <p>P.T.O.</p>	<p>AGARD-AR-277</p> <p>All weather aviation Atmospheric disturbances Visibility Ice formation Electromagnetic environments Military aircraft</p>
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